System of Systems (SoS) Quality Attribute Specification and Architecture Evaluation

SEI Webinar
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Report Documentation Page

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Mike Gagliardi has more than 25 years experience in real-time, mission-critical software architecture and engineering activities on a variety of DoD systems. He currently works in the SEI Research, Technology, and System Solutions Program on the Architecture-Centric Engineering Initiative, and is leading the development of architecture evaluation and quality attribute specification methods for system and SoS architectures.

Leveraging Our Success in Software Architecture

We have lots of experience and success with proven methods for quality attribute elicitation (QAW*) and architecture evaluation (ATAM**) of software architectures, in many contexts:

- DoD
- Commercial
- Acquisition

These methods have been adopted by a wide variety of organizations to specify quality attributes and identify architectural risks early in the life-cycle.

We have expanded the scope to system and system-of-system (SoS) architectures.

*Quality Attribute Workshop
**Architecture Trade-off Analysis Method

SEI Software Architecture Axioms

1. Software architecture a bridge between business and mission goals and a software-reliant system.

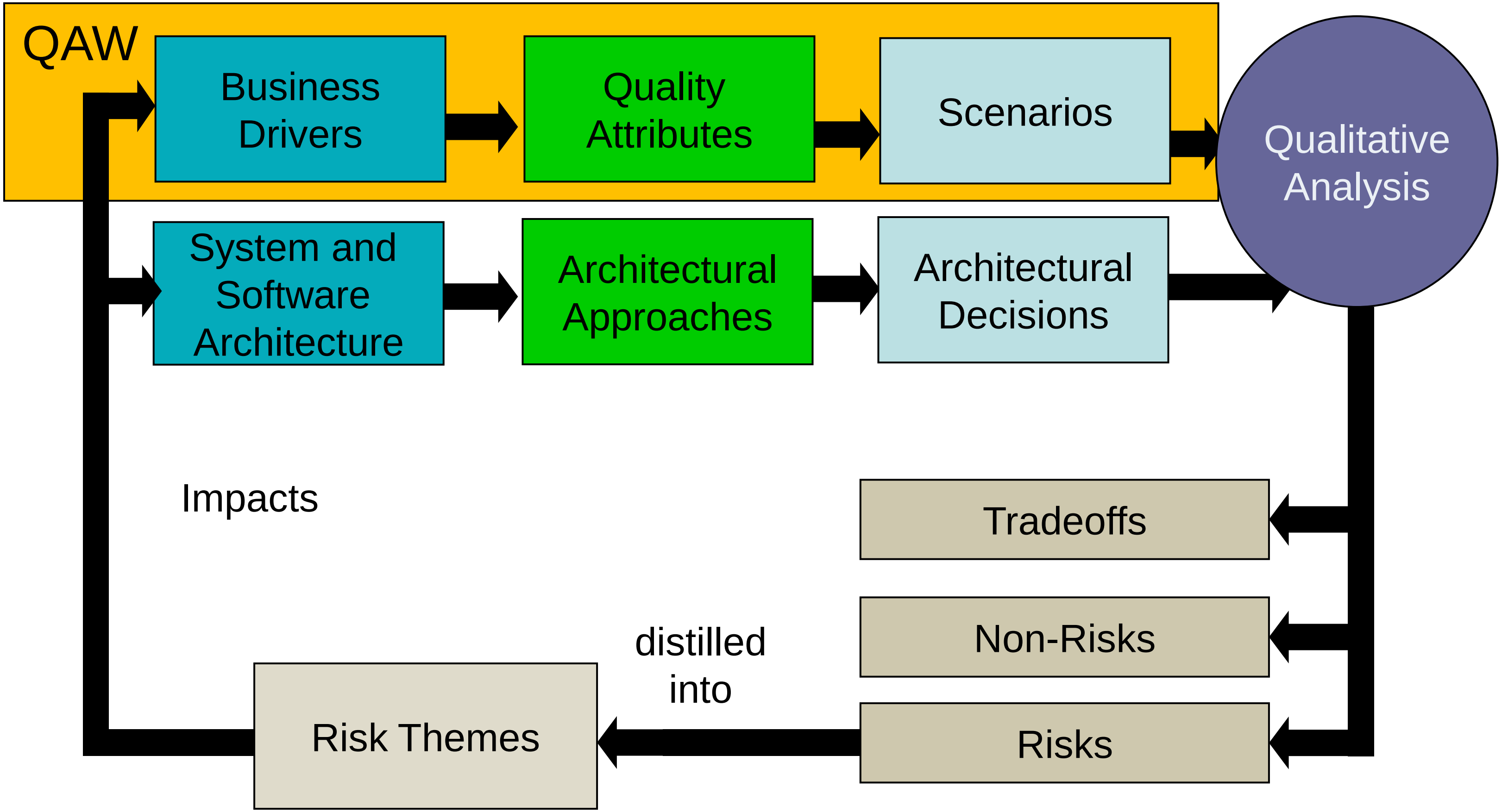
2. Quality attribute requirements drive the design of the software architecture.

   — Quality attribute requirements stem from business and mission goals.
   — Key quality attributes need to be characterized in a system-specific way.
   — Scenarios are a powerful way to characterize quality attributes and represent stakeholder views.

3. Software architecture drives software development throughout the life cycle.

   — Software architecture must be central to software development activities.
   — These activities must have an explicit focus on quality attributes.
   — These activities must directly involve stakeholders – not just the architecture team.

Conceptual Flow of System and Software ATAM



Concerns Addressed by Software Architecture

Achieving Key Properties in Software-Reliant Systems		
Design-time	**Run-time**	**Software In Its Environment**
• Modifiability • Maintainability • Reusability • Portability • Testability • Etc.	• Performance • Security • Reliability • Availability • Scalability • Interoperability • Throughput • Capacity • Etc.	• Usability • Supportability • Configurability • Sustainability • Buildability • Etc.

Problem

Integration and operational problems arise due to inconsistencies, ambiguities, and omissions in addressing quality attributes between system and software architectures. This is further exacerbated in an SoS.

- Example quality attributes: predictability in performance, security, availability/reliability, usability, testability, safety, interoperability, maintainability, force modularity, spectrum management.

Functionality and capability are important, but the architecture must be driven by the quality attributes. Identifying and addressing quality attributes early and evaluating the architecture to identify risks is key to success.

***Architecture plays an important role in every stage*.**

Common Symptoms Stemming From Architectural Deficiencies

Operational

- Communication bottlenecks under various load conditions in systems or throughout system of systems
- Systems that hang up or crash; portions that need rebooting too often
- Difficulty synching up after periods of disconnect and resume operations
- Judgment by users that system is unusable for variety of reasons
- Database access sluggish and unpredictable

Developmental

- Integration schedule blown, difficulty identifying root causes of problems
- Proliferation of patches and workarounds during integration and test
- Integration of new capabilities taking longer than expected, triggering breaking points for various resources
- Significant operational problems ensuing despite passage of integration and test
- Anticipated reuse benefits not being realized

The Need for Augmented Mission Threads in DoD SoS Architecture Definition

DoDAF is the SoS architecture framework for the DoD. It provides a good set of architectural views for an SoS architecture. However, it inadequately addresses cross-cutting quality attribute considerations.

System use cases focus on a functional slice of the system.

More than DoDAF and system use cases are needed to ensure that the SoS architecture satisfies its cross-cutting quality attribute needs.

SoS end-to-end mission threads augmented with quality attribute considerations are needed to help define the SoS Architecture precepts and guidelines, and then later evaluate the SoS architecture.

Definitions (DoD Context)

Vignette: A description of the geography, own force structure and mission, strategies and tactics, the enemy forces and their attack strategies and tactics, including timing. There may be associated Measures of Performance (MOP) and Measures of Effectiveness (MOE). A vignette provides context for one or more *mission threads*.

Mission Thread:
A sequence of end-to-end activities and events beginning with an opportunity to detect a threat or element that ought to be attacked and ending with a commander’s assessment of damage after an attack.
C4ISR for Future Naval Strike (Operational)

Sustainment: A sequence of activities and events which focus on development, deployment and maintenance.

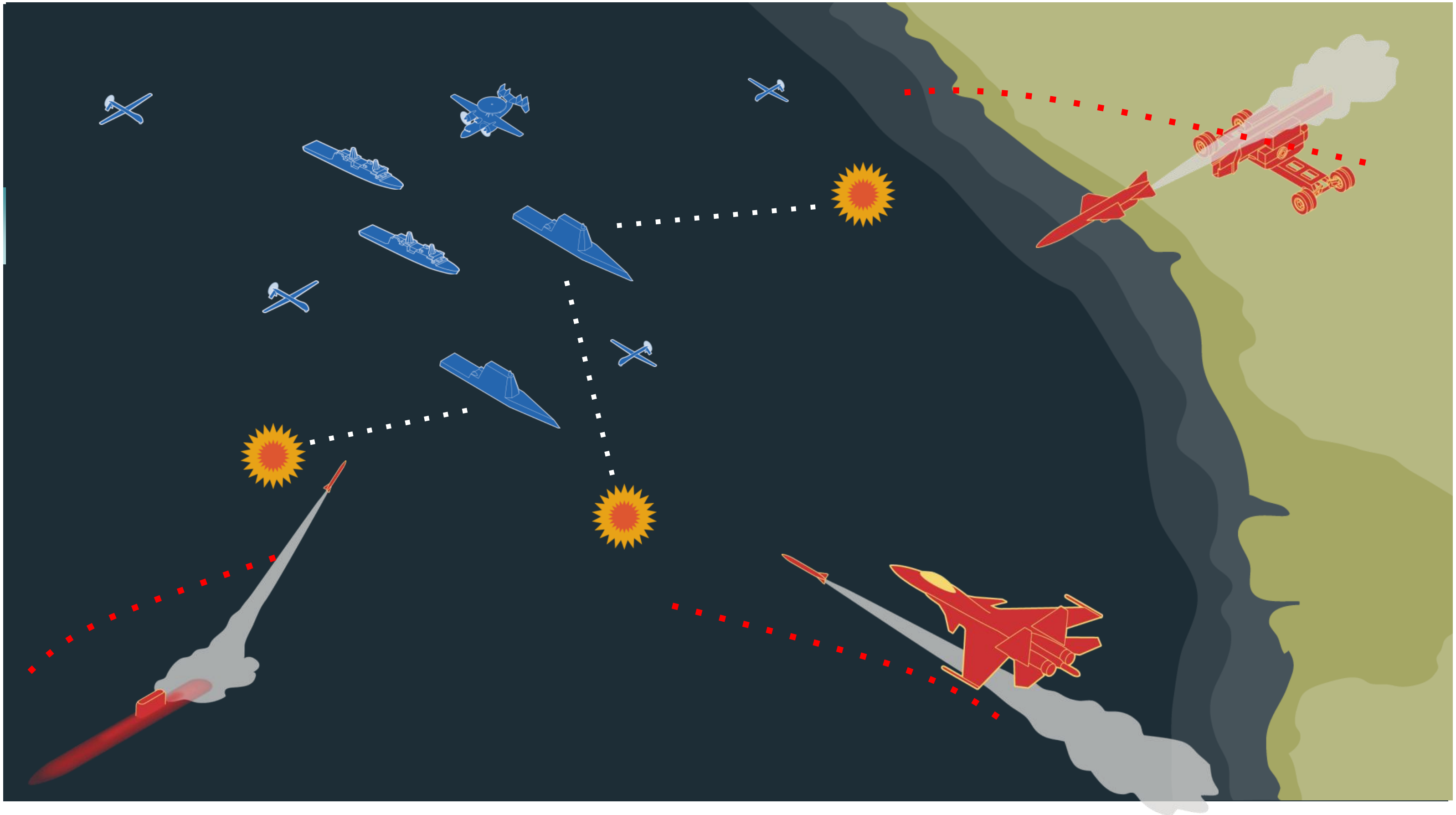
Vignettes Are the Starting Point – Example Wording

Two ships (Alpha and Beta) are assigned to integrated air and missile defense (IAMD) to protect a fleet containing two high-value assets (HVA). A surveillance aircraft SA and 4 UAVs are assigned to the fleet and controlled by the ships. Two UAVs flying as a constellation can provide fire-control quality tracks directly to the two ships. A three-pronged attack on the fleet occurs:

- 20 land-based ballistic missiles from the east
- 5 minutes later from 5 aircraft-launched missiles from the south
- 3 minutes later from 7 submarine-launched missiles from the west.

The fleet is protected with no battle damage.

Vignettes Are the Starting Point – Example Context



Mission Threads Flow from Vignettes – Example (Non-Augmented)

1. 20 land-based missiles launched - X minute window

2. Satellite detects missiles - cues CMDR

3. CMDR executes re-planning – reassigns Alpha and Beta

4. Satellite sends track/target data - before they cross horizon

5. Ships' radars are focused on horizon crossing points

…

N Engagement cycle is started on each ship

N+1. Aircraft are detected heading for fleet

N+2. SA detects missile launches – tells CMDR

N+3. CMDR does re-planning - UAVs are re-directed

N+4. FCQ tracks are developed from UAV inputs

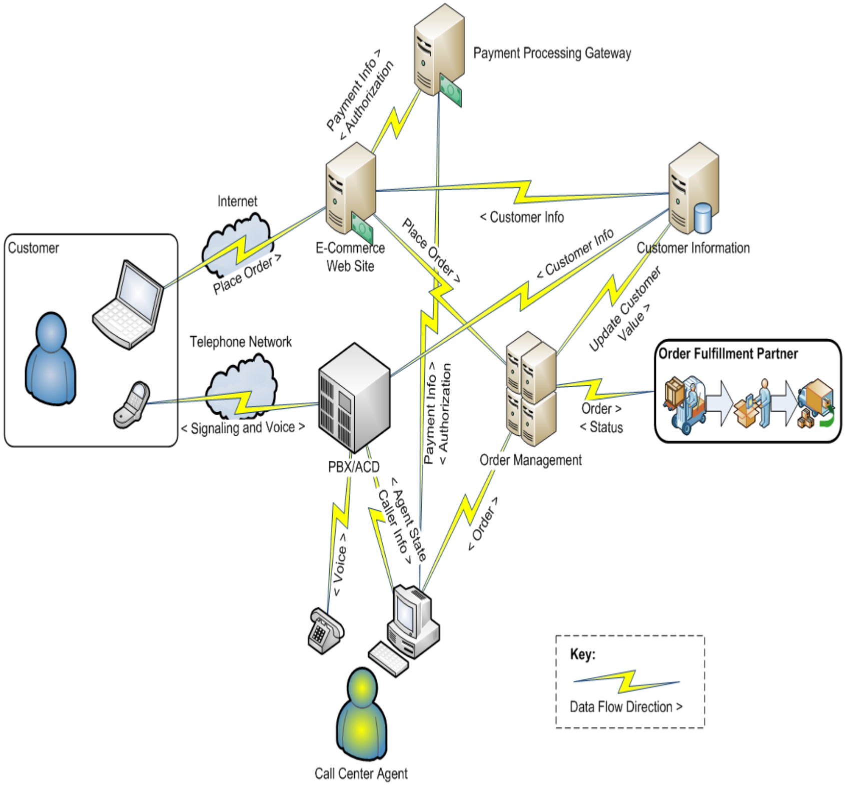
Other End-to-End Mission Threads

… have also proven useful in commercial SoS contexts, we have piloted this in:

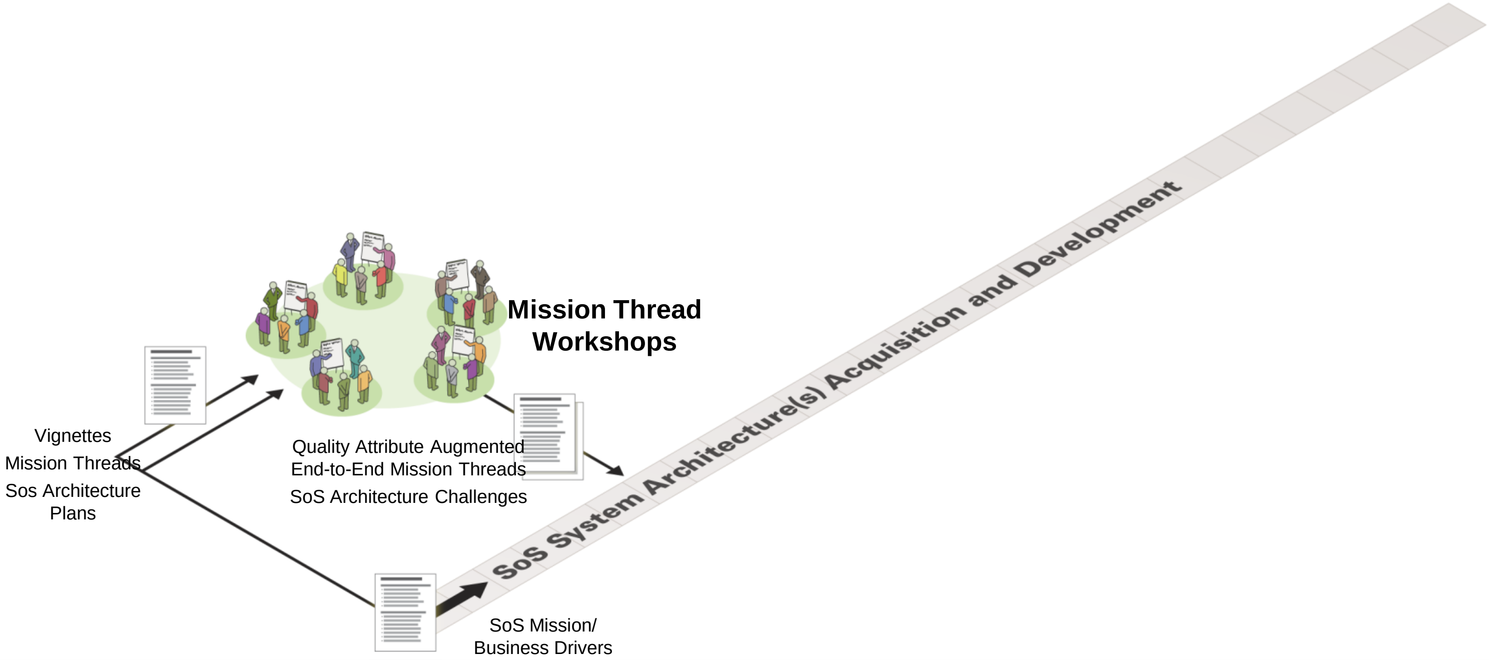
- Commercial Call-Center context
- Stock Market Transaction context

The methods hold up,
the inputs change:

- End-to-End Business Process Threads
- End-to-End Transaction Threads



Overview



Mission Thread Workshops

Vignettes

Mission Threads

Sos Architecture Plans

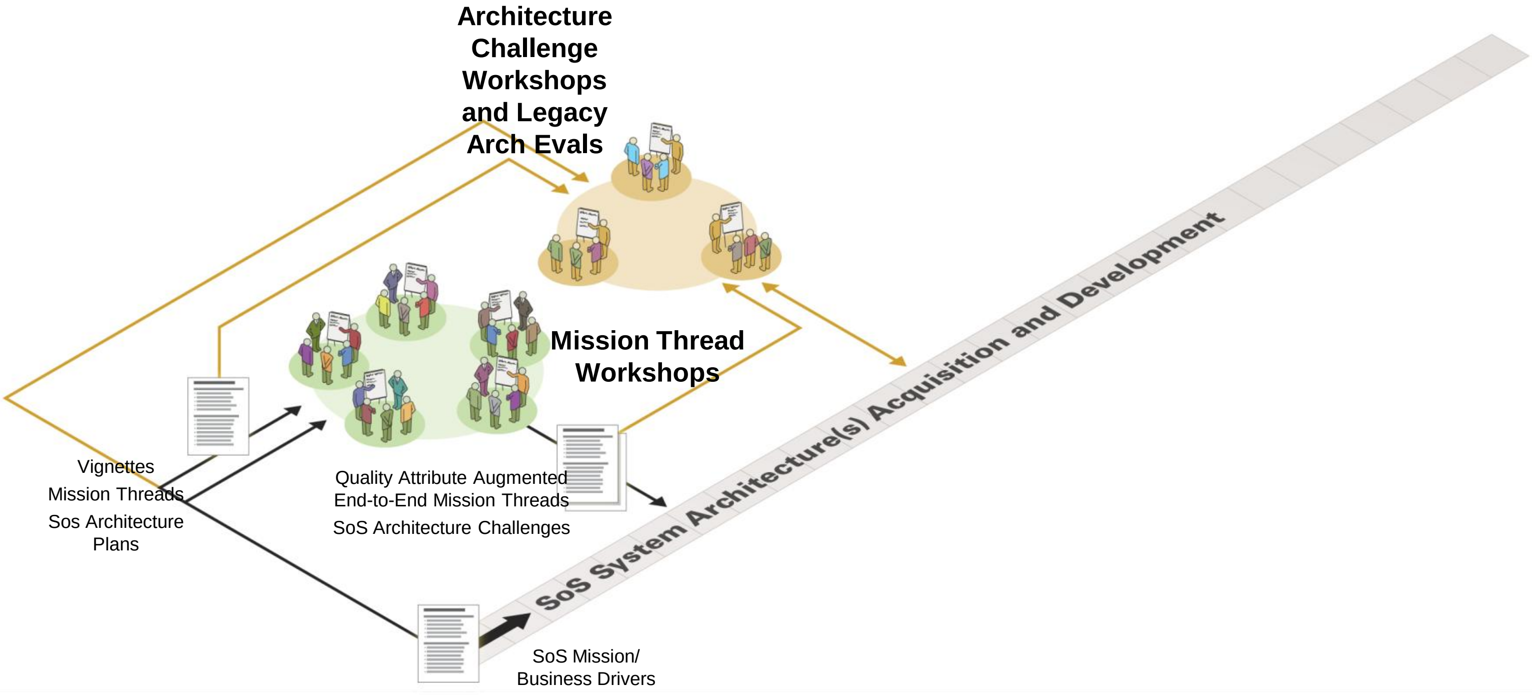
Quality Attribute Augmented End-to-End Mission Threads

SoS Architecture Challenges

SoS Mission/ Business Drivers

SoS System Architecture(s) Acquisition and Development

Overview


Architecture Challenge Workshops and Legacy Arch Evals
Mission Thread Workshops
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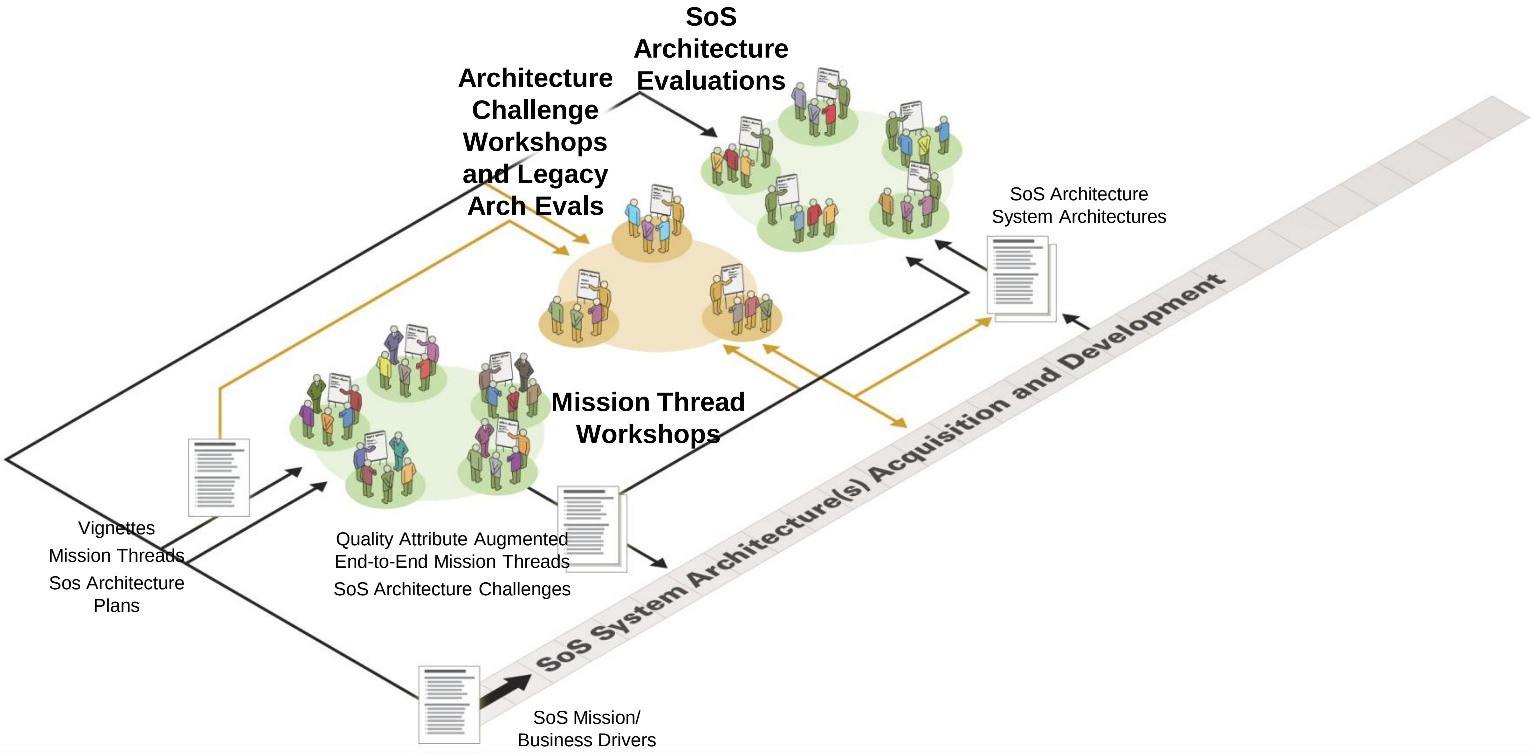
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SoS Mission/ Business Drivers

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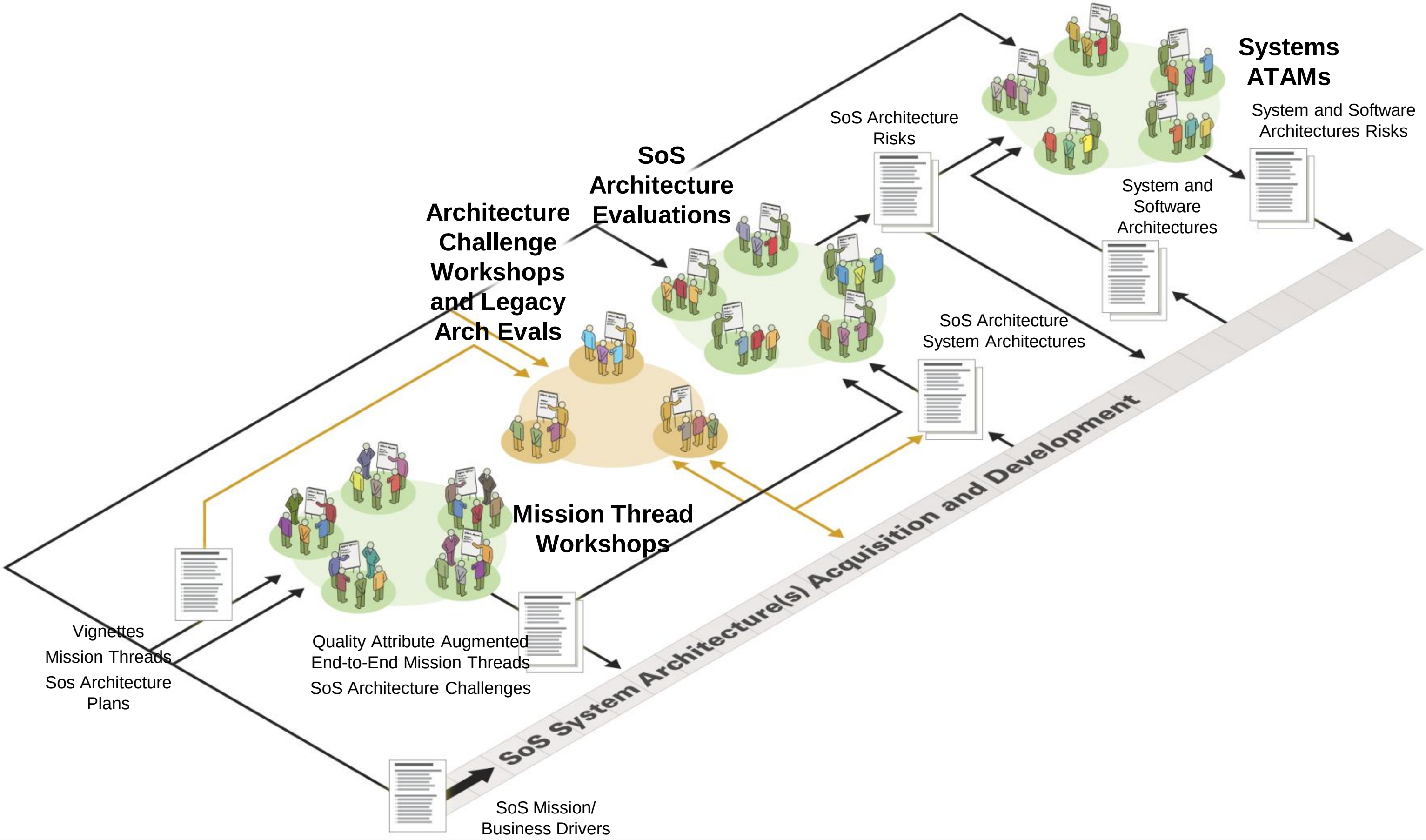

Systems
ATAMs
System and Software
Architectures Risks
SoS Architecture
Risks
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Architecture
Evaluations
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End-to-End Mission Threads
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SoS Mission/
Business Drivers

Mission Thread Workshop

Mission Thread Workshop (MTW) Purpose

The MTW ***augments SoS mission threads*** with quality attribute considerations that shape the SoS architecture and ***identifies SoS architectural challenges***, as early in the SoS development cycle as possible.

The mission thread augmentation is performed with inputs from key SoS stakeholders and is facilitated by the SEI.

The augmented mission threads and challenges are used to develop the SoS architecture and then later to evaluate the SoS architecture.

There will be a series of MTWs depending on scope, scale, and schedule considerations.

MTW sequence planning/scheduling and vignette and MT development/selection

Criteria for development/selection of vignettes and MTs

- Capability Coverage
- New requirements/capabilities
- Stressing the SoS
  - constituent systems, communications, etc
- New integrated existing capabilities

You can only do so many of these… make them count.

Preparation

The SoS Program Manager develops a overview presentation on the SoS Mission / Business Drivers (see SoS Mission / Business driver presentation template).

The SoS Architect develops an overview presentation on the SoS Architecture Plans (see SoS Architecture Plans presentation template).

The SEI meets with the SoS Architect and PM to:

- Determine if the vignettes and MTs are sufficient to proceed.
- Provide feedback on the two presentations
- Reach agreement on scope and series of MTWs
- Identify Stakeholders
- Determine logistics

Stakeholders are Key!

When developing the initial set of vignettes and MTs, it is critical to associate them with the key stakeholder types that will be necessary to participate in the Workshops.

There may be groups of stakeholder types that are not necessary for specific vignettes.

Example stakeholders: (leads in the following)

- Modeling and Simulations
- Integration and Test Facility (SIL)
- CONOPS, DRM, Operational Analysts,
- SoS, System and Software Architects
- Legacy System Architects

MTW Inputs - 1

SoS Business and Mission Drivers Presentation (15 mins)

- A representative from the SoS stakeholder community presents the SoS business and/or mission drivers including the business/programmatic context, high-level functional requirements, high-level constraints, high-level quality attributes, acquisition strategy, etc.

SoS Architecture Plans Presentation (30 mins)

- The SoS architect presents the architecture development plans including key business/programmatic requirements, key technical requirements and constraints that will drive architectural decisions, any relevant existing context diagrams, high-level SoS diagrams and descriptions, development spirals and integration schedule.

MTW Inputs - 2

Vignettes

- A description of the geography, own force structure and mission, strategies and tactics, the enemy forces and their attack strategies and tactics, including timing. There may be associated Measures of Performance (MOP) and Measures of Effectiveness (MOE).
  - An SoS will typically support multiple vignettes, i.e. multiple mission areas such as Air Defense, Ballistic Missile Defense, Replenishment, Mobility, etc.
  - Each vignette typically supports multiple mission threads

Mission Threads, types:

- Operational - A sequence of activities and events beginning with an opportunity to detect a threat or element that ought to be attacked and ending with a commander's assessment of damage after an attack.
- Sustainment: A sequence of activities and events which focus on development, deployment and maintenance.

Typical MTW Agenda

08:00-08:15	Welcome/Introductions/Opening Remarks (joint)
08:15-08:45	MTW Overview (SEI)
08:45-09:00	Business Drivers and Quality Attributes (Architect)
09:00-09:40	OV-1 & Vignettes Overview (Architect)
09:40-09:55	Break
09:55-12:00	Augmentation of 1st mission thread (SEI facilitated)
12:00-13:00	Lunch
13:00-13:20	Review OV-1 and vignette associated with 2nd mission thread (Architect)
13:20-15:00	Augmentation of 2nd mission thread (SEI facilitated)
15:00-15:15	Break
15:15-15:45	Review OV-1 and vignette associated with 3rd mission thread (Architect)
15:45-17:00	Augmentation of 3rd mission thread (SEI facilitated)

Augmentation Process – Per Mission Thread

1) For each event in the mission thread:
   - Elicit quality attribute considerations. Capturing any engineering issues, assumptions, challenges, additional use case and mission threads (with QA context etc.)
   - Capture any capability and/or mission issues that arise.

2) Elicit any over-arching quality attribute considerations
   - Capturing any over-arching assumptions, engineering issues, challenges, additional use cases and mission threads (with QA context) etc.

3) Capture any capability and/or mission issues that arise.

4) Capture any MT extensions for a later pass.

Parking Lot – for organization, programmatic, non-technical issues that arise (will not be further pursued in the MTW).

SEI facilitates and scribes using a pre-defined MTW template.

Stakeholder Inputs are Key.

Rules

SEI will provide the facilitation and scribing.

This is a big crowd: side conversations, cell calls, etc. will not be allowed to disrupt the meeting.

Once an issue is identified and discussed, we will not allow it to be re-discussed. It will be noted at the appropriate place.

Will keep the discussions within scope.

Will not get into the details of potential solutions to issues.

Programmatic, organizational, and other non-technical issues will be noted, but not discussed in detail.

Example MTW Walk-Through

At this point, we will switch to the MTW template which is partially filled in. We will walk through the MTW augmentation process using the DoD SoS example.

MTW Outputs

Individual MTWs

- Augmented Mission Threads
  - Over-arching quality attribute augmentations for the mission thread
  - Capability and mission augmentations to the mission thread
  - Quality attribute augmentations for each event in the mission thread
  - Identified mission/additional use cases (with context) and mission threads

- Challenges
  - Architectural, capability and mission challenges derived from the mission thread augmentations.
  - The MTW team will roll up challenges from the data and provide an out-brief of the challenges.
    - Mapped to contributing augmented mission thread steps
    - These are vetted and updated with the principals
  - Identify any candidate legacy system architecture that may require architecture evaluation.

SoS Architectural Challenges

- Report upon completion of series of MTWs:
  - SoS architectural challenges derived and rolled up from the mission thread augmentations; upon completion of the series of mission thread workshops for the SoS.
  - Meet with the principals to “rack and stack” challenges.

Examples of Rolled-up Challenges

End-End resource management strategy needs developed; esp. regarding issues dealing with supporting the number of missiles and radar coverage.

Fault model and recovery activities needs further definition and architectural guidance needs developed

Degraded modes of operation strategy and associated architectural support needs developed.

Performance timelines and deadlines need defined and decomposed

Manning/automation studies/analyses insufficient

Sensor coordination between the two ships and the UAVs needs further analysis.

MTW Experiences – 1

Conducted a total of 22 MTWs (over 60 mission threads augmented), each MTW is a 1.5 day meeting

Plan 4 MTs per MTW, but expect to augment 3.

Expect 25-30 stakeholders to want to participate per MTW. Benefits from strong facilitation and independent 3rd party leadership.

Clients developed very good first pass vignettes and MTs after initial introduction.

Criteria for MT selection include: New capability, High perceived risk, proposal differentiators, etc.

DoDAF OV-1's were sufficient level of documentation going into the MTWs

MTW Experiences - 2

DoDAF OV-1’s were sufficient level of documentation going into the MTWs

Mission thread step elaboration focused on:

- Command authority, network communications, step constraints
- Manned vs Automated, timelines, planning considerations
- Availability and Survivability considerations
- Readiness, environmental conditions, start up/shut down
- Current capabilities/extensions
- CONOPS considerations
- Assumption clarifications and issues

MTW Experiences - 3

Quality Attributes Considerations:

- Timeline decomposition often built into thread (weeks to seconds)
- Availability/ Degraded Operation / Resource Management under-developed
- Focus on operational MTs, separate MTW for development and support
- Over-arching MT pass collects much of the QA considerations
- Identified additional use cases and MTs (e.g. survivability)

Challenges:

- Some challenges need to be kicked up to the SoS architecture level to address, while others need to be addressed by systems engineering
- Drives an SoS Architecture and Guidelines Document

MTW – Initial Results - 1

The MTW and SoS Arch Evaluation methods adopted by a Navy SoS organization and required in their architecture development process

Many of the identified challenges drove early risk mitigation activities (e.g. prototyping, EDM, white papers, modeling and sim).

Many new use cases and additional mission threads identified. The QA considerations will be included in the use cases.

Excellent vehicle to promote communication between architects and stakeholders.

Capability and Mission Challenges were identified as well as Architectural Challenges.

MTW – Initial Results - 2

SoS Architecture and Guidelines document is needed. Developed a template for use on Army and Navy SoS Programs.

Supports programs' DoDAF architecture development efforts. Normalized the OV-1s and informed and drove many subsequent DoDAF views (e.g. OV-5, OV-2, OV-3, OV-4, OV-6c, SV-5a, SV-4a, SV-1, SV-3)

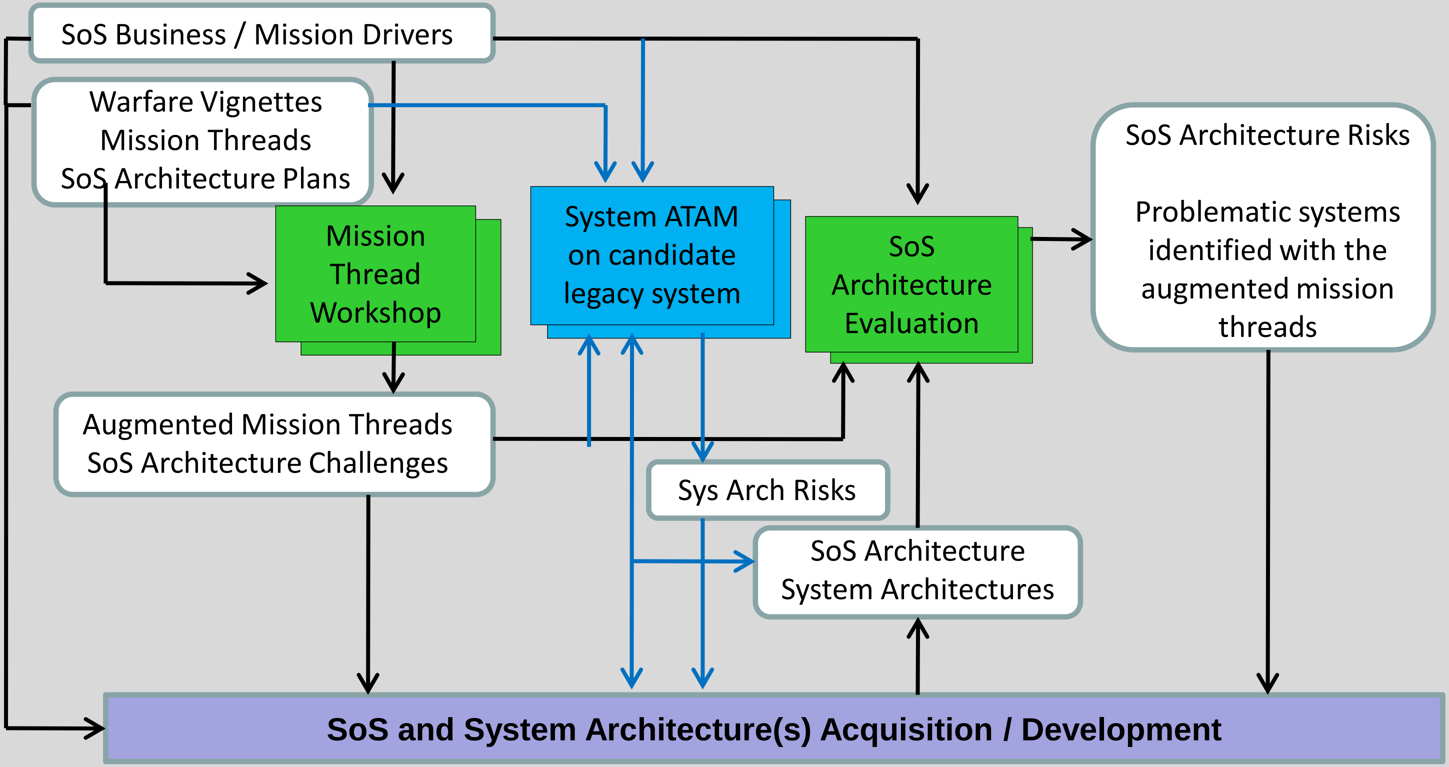
3rd Party facilitation by the MTW facilitators enabled the leads to think about and participate in the discussions rather than trying to lead/control the meetings

Method worked for non-software elements, as well as software-intensive elements

Legacy System Architecture Evaluation Using ATAM

Legacy System Architecture Evaluation - Early

- Early elicitation of quality attribute considerations
- **Early identification and addressing of architecture challenges (e.g. candidate legacy system architecture evaluation)**
- Early identification and mitigation of architectural risks



SoS Business / Mission Drivers
Warfare Vignettes
Mission Threads
SoS Architecture Plans
Mission Thread Workshop
System ATAM on candidate legacy system
SoS Architecture Evaluation
SoS Architecture Risks
Problematic systems identified with the augmented mission threads
Augmented Mission Threads
SoS Architecture Challenges
Sys Arch Risks
SoS Architecture System Architectures
SoS and System Architecture(s) Acquisition / Development

Purpose of the System ATAM

The System ATAM is a method that helps stakeholders ask the right questions to discover potentially problematic architectural decisions.

Purpose is to assess the consequences of **system and software architectural** decisions in light of quality attribute requirements and business goals; and to identify architectural risks.

The purpose is **NOT** to provide precise analyses; the purpose **IS** to discover risks created by architectural decisions.

Discovered risks can then be made the focus of mitigation activities.

Tradeoffs can be explicitly identified and documented

Using the augmented mission threads to seed the system architecture evaluation

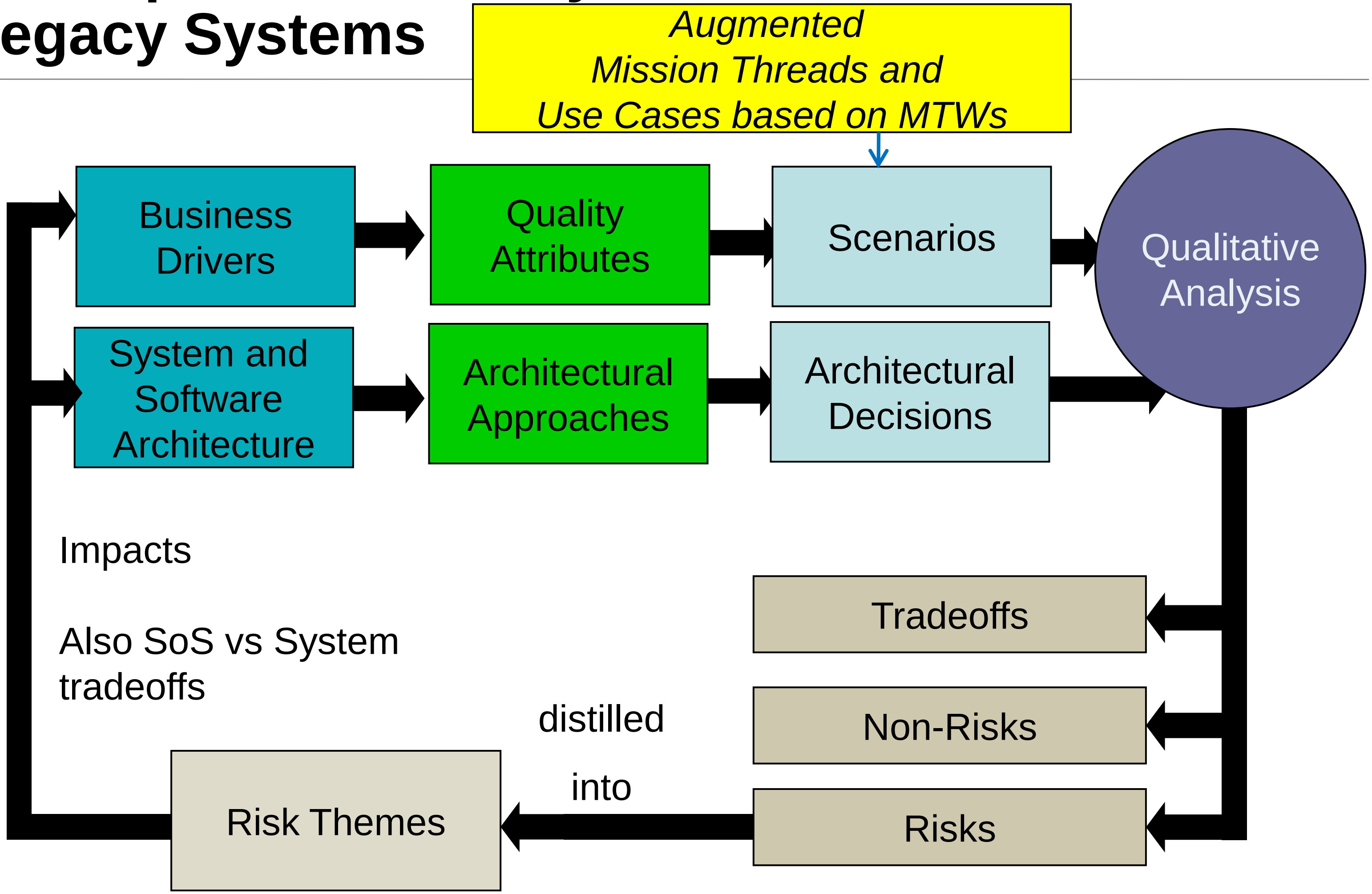
Comments from augmented mission thread:

- The Defensive Engagement System may not be able to support the deconfliction timeline for 5 incoming missiles.
- The Defensive Engagement System may not have the capability to acknowledge Beta’s acceptance of its assignment of 2 missiles.
- Is the Defensive Engagement System capable of sending track updates to the interceptor missiles that Beta had launched within the intercept timeline?

In preparation, the System ATAM lead meets with SoS and appropriate system architects to discuss what is in and out of scope concerning the system under analysis and if appropriate documentation exists.

Agreement is reached on the scenarios)based upon the augmented mission threads) with the understanding that additional scenarios can be added during the legacy system architecture evaluation.

Conceptual Flow of System ATAM Variant for Legacy Systems



Examples of Scenarios

Scenarios address both system and software aspects. Consist of Stimulus, Environment and Response.

Growth scenarios

The Defensive Engagement System (DES) is able to support de-confliction of 7 incoming missiles using own-ship and external information within 5 seconds.

An upgraded DES is able to reduce the confliction time by 40% of 7 incoming missiles with no loss of existing functionality.

Exploratory scenario

The DES is able to operate at up to 80% of its time budget for de-confliction of 7 incoming missiles with 8 coalition UAVs and 3 coalition helicopters operating in its vicinity.

Stakeholders and Evaluators

Stakeholders will consist of:

- System Architects of relevant, associated systems to system under evaluation
- SoS Architects who know the total system and how the system under evaluation is envisioned to fit in
- Relevant stakeholders of the system under evaluation in the areas of requirements, development, T&E, sustainment, M&S

ATAM evaluators will look to identify/expose potential system and software architecture risks, with the help of the stakeholders. Subject matter experts may be used on the evaluation team, if necessary.

Walk-through of a scenario derived from augmented MT

The Defensive Engagement System (DES) is able to support de-confliction of 7 incoming missiles using own-ship and external information within 5 seconds.

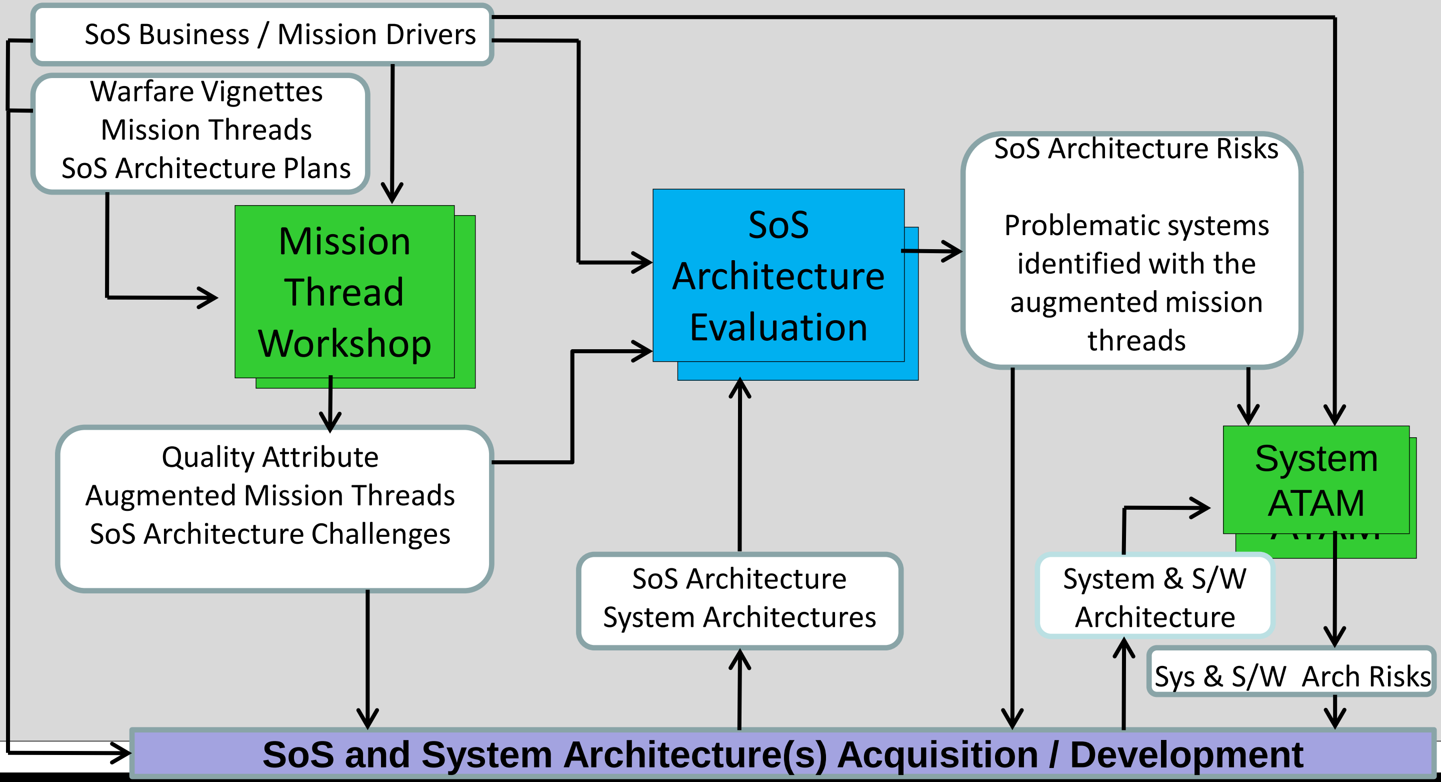
- System architect identifies that currently DES can support 3 incoming missiles with 25% spare capacity given the existing hardware.
- The software architect reveals that the system has a monolithic software architecture which is tightly coupled to the existing hardware.
- The architect identifies that upgraded hardware is available for the system which will provide the needed performance upgrade, but the software will need to be re-designed to take advantage of the upgrade.

SoS and DES architects and managers negotiate how to proceed based on architectural risks identified and associated risk mitigation options.

SoS Architecture Evaluation

SoS Architecture Engagement

- Early elicitation of quality attribute considerations
- Early identification and addressing of architecture challenges
- Early identification and mitigation of architectural risks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System & S/W Architecture
Sys & S/W Arch Risks
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SoS Architecture Evaluation Purpose

The SoS Architecture Evaluations ***identifies SoS architectural risks*** by probing the SoS architecture, using the augmented SoS mission threads and challenges, to evaluate the SoS architecture. It also ***identifies any problematic systems that require further evaluation***.

There will be a series of SoS Architecture Evaluations depending on scope, scale, and schedule considerations.

Stage 1: Preparation - 1

Review results of MTW, noting the architectural challenges and expected resolutions; and highlight augmentations that require further explanation

Identify the mission threads for the SoS Arch Eval with the SoS architect

- Assume that only 1-2 mission threads can be evaluated per day max.

Develop and review the SoS business/mission drivers and the SoS and System/SW architecture presentations

Review SoS and system architecture documentation for sufficiency

Identify stakeholders (some to assist with the evaluation)

Stage 1: Preparation - 2

Develop a schedule of the evaluations

Set up logistics and send out read-ahead with invitations

Walk-through one mission thread for practice

Identify evaluation team

- Lead, Scribe, 3 Evaluators
  - ATAM evaluator qualified
- Domain SMEs (e.g. Communications, sensors, weapons, platforms, warfare experts)

Evaluation team reviews the inputs and becomes familiar with the SoS Architecture in advance of the evaluation

Stage 2: Execution - 1

Note: 2 day max for each SoS Arch Eval

- Probably will only get through 2 mission threads

Presentations:

- SoS Business/Mission Driver Presentation
- SoS Architecture Presentation
- Augmented Mission Threads for this evaluation
- Architectural Challenges from the MTW

Stage 2: Execution - 2

Analysis for each architecture challenge

- The architect describes how the architecture satisfies each architecture challenge indentified in the MTWs

Analysis for each augmented mission thread

- Start with SoS Architect
- Walkthrough the documented architecture, describing how the architecture satisfies the MT
  - Step by step probing all highlighted QAs, looking for risks
  - Some hybrid of completing a step for all QAs and completing all steps for a QA.

For each analysis above:

- SoS architect can hand over to system and s/w architects as needed
- The evaluation team probes for risks
- Scribe risks, non-risks and issues, etc using the evaluation template

Stage 2: Execution - 3

Strong facilitation to stay on track; Do not go too deep in system architectures, whatever is architecturally significant for the MT at the SoS level.

Create "Parking Lot" for non-technical issues

Summarize findings in an out-brief

Stage 3: Roll-up and Follow-up

At the end of each SoS Arch Eval:

- Output Briefing
  - SoS Architectural Risk Themes, Non risks, Trade-offs
  - Any non-architectural issues discovered
  - One example of an mission thread analysis with discovered SoS architectural risks, trade-off points and non-risks
  - Any problematic systems identified for future
  - Identify “parking lot” issues
- Summary Report of individual SoS Arch Eval
  - Detailed write-ups on the risk themes, non-risks, etc found during the evaluation
  - Summary of the SoS architecture, approaches, guidelines, etc
  - Summary of the SoS business and mission drivers, quality attributes, summarizing implications of any mismatches between SoS and systems

SoS Arch Evals Roll-up

At the end of the series of SoS Arch Evals

- Evaluation team meets to roll-up the findings from the series of SoS Arch Evals
- Annotated Summary Briefing
  - SoS Architectural Risk Themes and Non-risks (rolled up)
  - Any non-architectural issues discovered (rolled up)
  - Identify problematic areas and schedule “focused” architecture evaluations (e.g. System & Software ATAM)
  - Recommendations
- SoS Arch Eval Summary Report
  - Detailed write-ups on the risk themes, non-risks, etc found during the evaluation
  - Summary of the SoS architecture, approaches, guidelines, etc
  - Summary of the SoS business and mission drivers, quality attributes, summarizing implications of any mismatches between SoS and systems
  - Recommended Next Steps

Value to Customers at Various Stages - 1

Working early with the Program Office to develop the proper architecture-centric acquisition strategy and associated language for proposals, contracts, etc. will

- drive the contractors to do the right thing architecturally early
- provide visibility to the program office into the architecture's goodness
- identify architectural risks early

This is the biggest point of leverage within DoD programs. We have demonstrated its effectiveness on DoD programs in software architecture. Our many pilots indicate that this is true for SoS and system architecture as well.

Value to Customers at Various Stages - 2

MTW - Early elicitation of SoS quality attribute needs, architectural challenges, mission and capability challenges, system use cases.

- Stakeholder-elicited quality attribute information available to the SoS architecture developers (and integrators and testers); also used to inform the system and software architecture development/acquisition activities.
- Challenges are identified early in the life cycle, to prevent them from becoming risks later.

Architecture Evaluation - Early identification of SoS architecture risks and problematic constituent systems.

- The architects, along with the program office, can identify, prioritize, and mitigate risks early in the life cycle, prior to integration.
- Addressing the risks prior to integration will reduce integration and operational risks.

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Questions

BACKUPS

Definitions - 1

A **System of Systems** is "a set or arrangement of systems that results when independent and useful systems are integrated into a larger system that delivers unique capabilities." [OSD Systems Engineering Guide for Systems of Systems, August 2008]

OSD SE Guide defines four types of SoSs:

- Directed
- Acknowledged
- Collaborative
- Virtual

The tutorial will be addressing Directed and Acknowledged SoSs

Definitions - 2

Directed. Directed SoS are those in which the integrated system-of-systems is built and managed to fulfill specific purposes. It is centrally managed during long-term operation to continue to fulfill those purposes as well as any new ones the system owners might wish to address. The component systems maintain an ability to operate independently, but their normal operational mode is subordinated to the central managed purpose.

Acknowledged. Acknowledged SoS have recognized objectives, a designated manager, and resources for the SoS; however, the constituent systems retain their independent ownership, objectives, funding, and development and sustainment approaches. Changes in the systems are based on collaboration between the SoS and the system.

Collaborative. In collaborative SoS the component systems interact more or less voluntarily to fulfill agreed upon central purposes. The Internet is a collaborative system. The Internet Engineering Task Force works out standards but has no power to enforce them. The central players collectively decide how to provide or deny service, thereby providing some means of enforcing and maintaining standards.

Virtual. Virtual SoS lack a central management authority and a centrally agreed upon purpose for the system-of-systems. Large-scale behavior emerges—and may be desirable—but this type of SoS must rely upon relatively invisible mechanisms to maintain it.

Definitions - 3

An **Architecture** is the structure of components, their relationships, and the principles and guidelines governing their design evolution over time [IEEE Std 610.12 and DoDAF].

*An **SoS Architecture** is the structure of constituent systems, their relationships, and the principles and guidelines governing their design evolution over time.*

Need to elaborate on this to clarify.

Elaboration

The structure(s) of the constituent systems include:

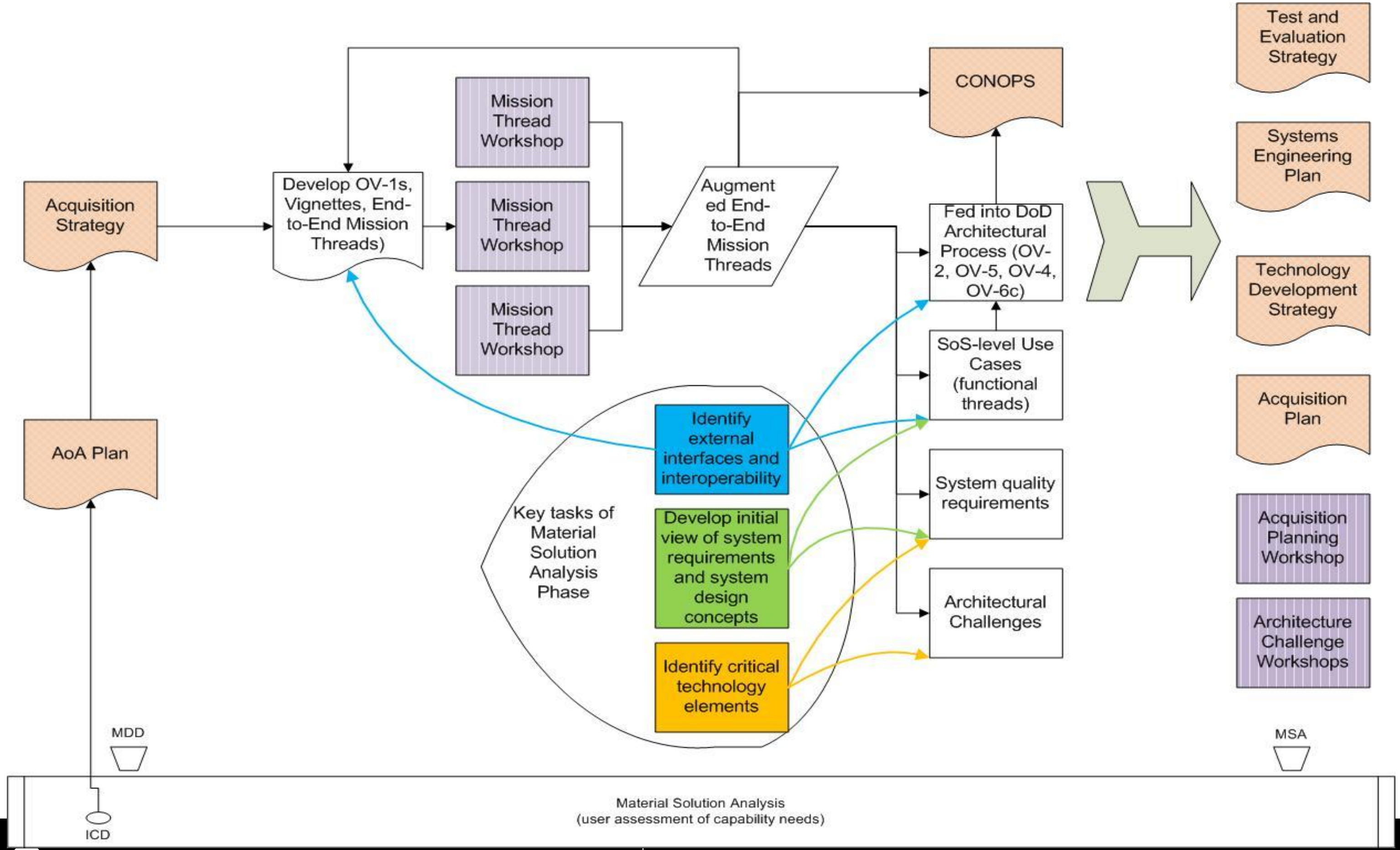
- Allocation of functionality to each constituent system
- End-to-end activity flows and communications, including operational, sustainment, development, and deployment activities.
- Externally visible properties and interfaces of the constituent systems, including behaviors, dependencies, use of shared resources, etc.
- Relationship among organizational entities and the constituent systems at each phase of the SoS lifecycle.
- Rationale and governance policies, for example, criteria for decisions about constituent system inclusion, continued participation and termination.

Depending on the type of SoS:

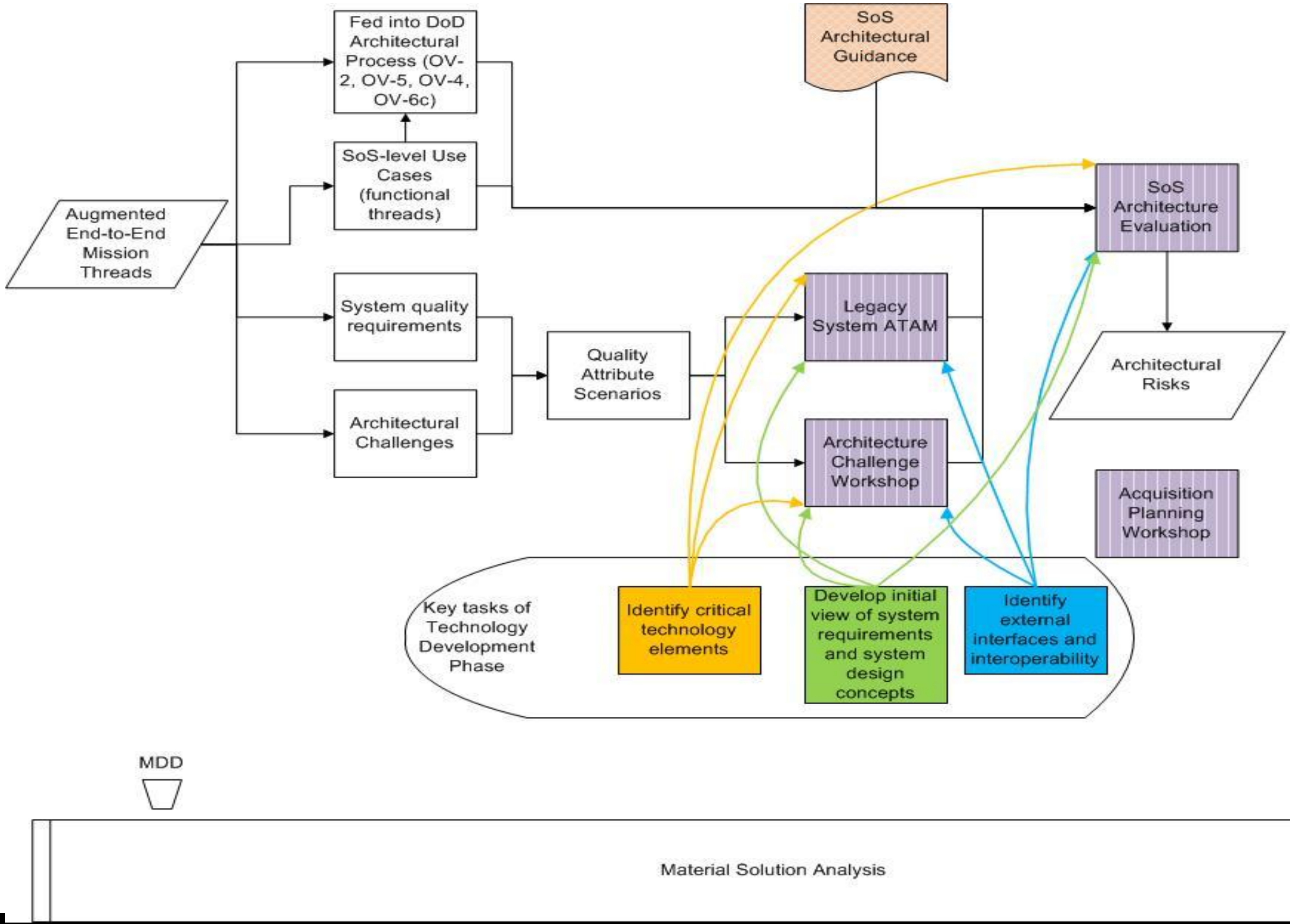
- the point at which the structures are determined and by whom can vary
- the level of specificity and abstractions can vary

Methods/Activities Superimposed Over DoD SoS Life-Cycle

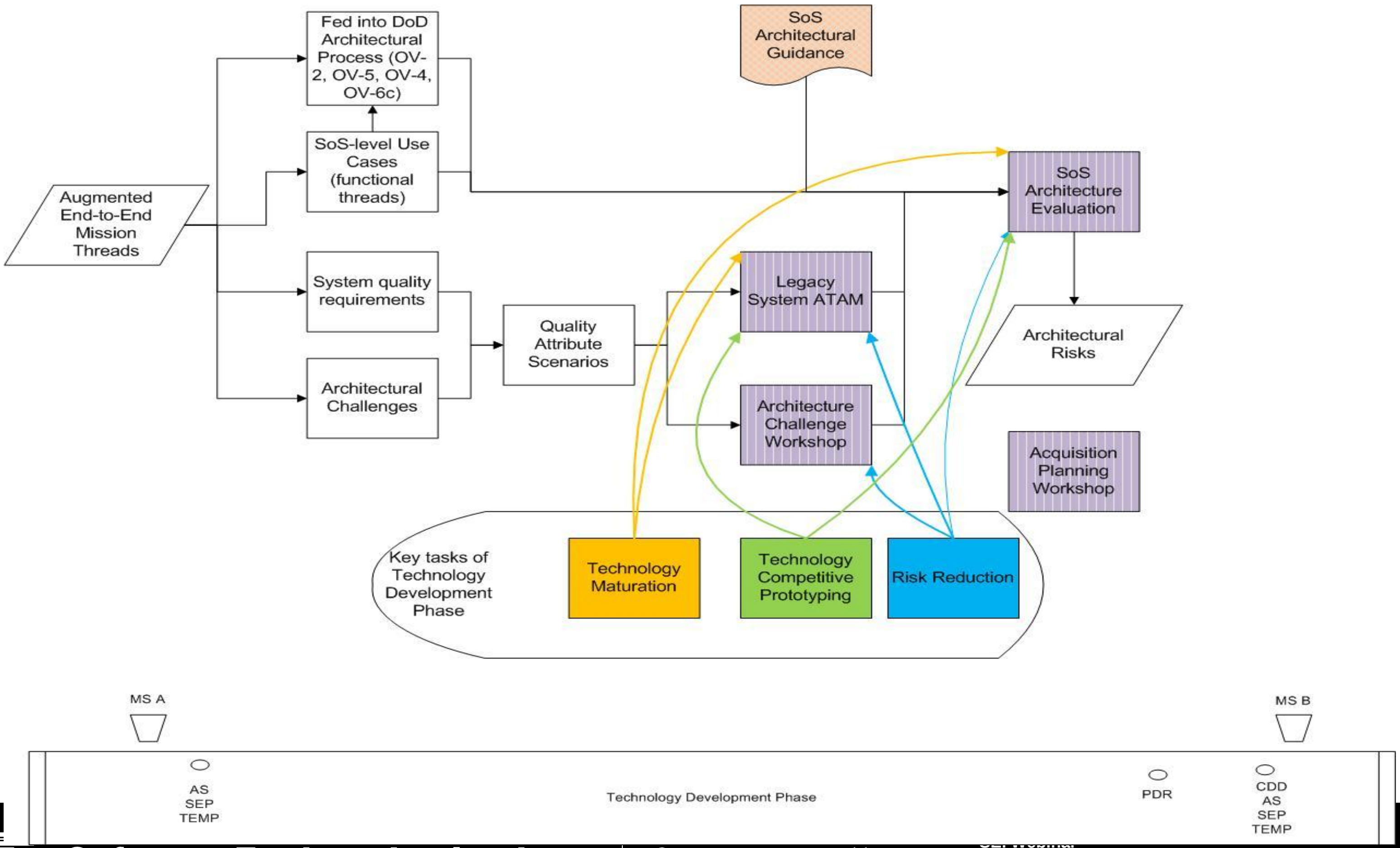
Material Solution Analysis Phase


Acquisition Strategy
AoA Plan
Develop OV-1s, Vignettes, End-to-End Mission Threads)
Mission Thread Workshop
Mission Thread Workshop
Mission Thread Workshop
Augmented End-to-End Mission Threads
CONOPS
Fed into DoD Architectural Process (OV-2, OV-5, OV-4, OV-6c)
SoS-level Use Cases (functional threads)
System quality requirements
Architectural Challenges
Key tasks of Material Solution Analysis Phase
Identify external interfaces and interoperability
Develop initial view of system requirements and system design concepts
Identify critical technology elements
Test and Evaluation Strategy
Systems Engineering Plan
Technology Development Strategy
Acquisition Plan
Acquisition Planning Workshop
Architecture Challenge Workshops
MDD
MSA
ICD
Material Solution Analysis
(user assessment of capability needs)

Material Solution Analysis Phase


Fed into DoD Architectural Process (OV-2, OV-5, OV-4, OV-6c)
SoS Architectural Guidance
SoS-level Use Cases (functional threads)
Augmented End-to-End Mission Threads
SoS Architecture Evaluation
System quality requirements
Legacy System ATAM
Quality Attribute Scenarios
Architectural Risks
Architectural Challenges
Architecture Challenge Workshop
Acquisition Planning Workshop
Key tasks of Technology Development Phase
Identify critical technology elements
Develop initial view of system requirements and system design concepts
Identify external interfaces and interoperability
MDD
MS A
Material Solution Analysis

Technology Development Phase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SoS Architecture Evaluation
System quality requirements
Quality Attribute Scenarios
Legacy System ATAM
Architectural Risks
Architectural Challenges
Architecture Challenge Workshop
Acquisition Planning Workshop
Key tasks of Technology Development Phase
Technology Maturation
Technology Competitive Prototyping
Risk Reduction
MS A
MS B
AS
SEP
TEMP
Technology Development Phase
PDR
CDD
AS
SEP
TEMP